to specify what its constants would be, within a very slight margin of possible error. Moreover, ammonium manganous selenate hexahydrate is almost exactly isostructural with its rubidium analogue, a fact in line with the results afforded for all analogous pairs of ammonium and rubidium salts throughout both this monoclinic series and the rhombic series of simple salts, $R_2{}^{S}_{Se}O_4$.

Monoclinic Double Selenates of the Cadmium Group.

By A. E. H. Tutton, D.Sc., M.A., F.R.S.

(Received March 14, 1922.)

Like the manganese group, the cadmium group of hexahydrated double selenates consists of only three salts, those containing rubidium, cæsium, and ammonium, the potassium salt being incapable of preparation and apparently of existence. A potassium cadmium selenate with two molecules of water is obtained instead, and was described by Von Hauer in the year 1866, and by Topsøe in 1870.* Indeed, so near in this group is even the rubidium salt to the limit of existence that it has only been obtained at all after many and prolonged attempts. Moreover, it was only formed then in small quantity in the very coldest weather, the great majority of crystals even in these few crops having been those of the salt just referred to with other than six molecules of water. Almost as great difficulty has also been found in preparing the cæsium salt, and the crystals of both these alkali metallic salts of the hexahydrated group have always been white and opaque, so that no optical investigation has been possible. These salts, indeed, would appear never to have been previously obtained at all. Moreover, the ammonium salt, which was obtained by Von Hauer and measured by Topsøe,* affords crystals which are for the most part opaque, and are described by Topsøe as being porcelain-like. No optical investigation of them has ever previously been attempted; they were not included by Topsøe and Christiansen in their great work. The author has succeeded, however, in obtaining a very few crystals of ammonium cadmium selenate hexahydrate, which remained sufficiently transparent for the few hours, after their removal from the mother liquor, necessary to enable them to be subjected to a fairly complete optical investigation. The method followed was the rapid one used in the even more difficult case of potassium ferrous selenate.†

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* Haldor Topsøe, 'Krystallogr.-kem. Unders. o. de Selensure Salte,' Copenhagen, 1870.

† 'Phil. Trans.,' A, vol. 218, p. 401 (1919).

The cadmium selenate used in preparing the double salts was obtained by precipitating a solution of cadmium sulphate with a just adequate quantity of sodium hydrate, and dissolving the thoroughly washed precipitate in selenic acid. Equal molecular quantities of solutions of cadmium selenate and of the alkali selenate were then mixed, and the liquid at once filtered and set out for spontaneous evaporation and crystallisation, with the results just specified.

Rubidium Cadmium Selenate, $Rb_2Cd(SeO_4)_2 \cdot 6H_2O$.

Crystal System.—Monoclinic. Class No. 5, holohedral-prismatic.

Axial Angle.—$\beta = 105° 7'$.

Ratio of Axes.—$a : b : c = 0{\cdot}7402 : 1 : 0{\cdot}5026$.

Forms observed.—$b\{010\}$, $c\{001\}$, $p\{110\}$, $p'\{120\}$, $q\{011\}$, $r'\{\bar{2}01\}$, $o'\{111\}$.

Habit.—That characteristic of all the rubidium salts of the series, the faces of $q\{011\}$ being nearly as large as those of $c\{001\}$. But the faces of $r'\{\bar{2}01\}$ were generally developed to an unusually large extent, a feature which is also exhibited by the sulphur analogue, rubidium cadmium sulphate. A typical crystal is portrayed in fig. 1.

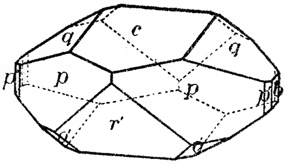

Fig. 1.—Typical crystal of rubidium cadmium selenate.

It was only after many attempts that measurable crystals were eventually obtained during nights of intense frost, and they were quite opaque, white like porcelain, even from the first. They were isolated crystals scattered here and there in the midst of a crop of transparent crystals of the di-hydrate. The angular measurements were made immediately after removal from the mother liquor, after careful drying with a fine linen cloth, and are quite trustworthy as far as are recorded in the accompanying Table; many other less trustworthy values were obtained, but are altogether discarded, as being below the standard of the author's work. Shortly afterwards the crystals became friable and crumbled to powder.

This hexahydrated salt thus appears to be metastable at the ordinary temperature, and even down to 0° C. or thereabouts, and decomposes to a more stable salt of lower hydration with considerable rapidity.

No cleavage was definitely ascertainable, and no density determinations of any value were possible. Optical investigation was quite impossible.

Interfacial Angles of Rubidium Cadmium Selenate.

Angle.		Mean observed.		Calculated.		Diff.
		°	′	°	′	′
ac	= (100) : (001)	—		74	53	
as	= (100) : (101)	—		45	44	
sc	= (101) : (001)	—		29	9	
cr′	= (001) : $(\bar{2}01)$	63	50	63	49	1
cs′	= (001) : $(\bar{1}01)$	—		38	35	
s′r′	= $(\bar{1}01)$: $(\bar{2}01)$	—		25	14	
r′a	= $(\bar{2}01)$: $(\bar{1}00)$	—		41	18	
r′c	= $(\bar{2}01)$: $(00\bar{1})$	116	10	116	11	1
ap	= (100) : (110)	—		35	33	
pp′	= (110) : (120)	—		19	28	
p′p‴	= (120) : (130)	—		9	58	
p′b	= (120) : (010)	—		34	59	
pp‴	= (110) : (130)	—		29	26	
p‴b	= (130) : (010)	—		25	1	
pb	= (110) : (010)	—		54	27	
pp	= (110) : $(1\bar{1}0)$	71	5	*		
pp	= (110) : $(\bar{1}10)$	108	55	108	55	0
cq	= (001) : (011)	25	53	*		
qb	= (011) : (010)	—		64	7	
qq	= (011) : $(01\bar{1})$	128	15	128	14	1
ao	= (100) : (111)	—		48	57	
oq	= (111) : (011)	—		27	29	
aq	= (100) : (011)	—		76	26	
qo′	= (011) : $(\bar{1}11)$	—		34	45	
o′a	= $(\bar{1}11)$: $(\bar{1}00)$	—		68	49	
co	= (001) : (111)	—		34	45	
op	= (111) : (110)	—		43	0	
cp	= (001) : (110)	77	45	*		
po′	= (110) : $(11\bar{1})$	—		57	29	
o′c	= $(11\bar{1})$: $(00\bar{1})$	—		44	46	
pc	= (110) : $(00\bar{1})$	102	15	102	15	0
bn	= (010) : (121)	—		54	15	
no	= (121) : (111)	—		15	57	
bo	= (010) : (111)	—		70	12	
os	= (111) : (101)	—		19	48	
bo′	= (010) : $(\bar{1}11)$	—		65	15	
o′s′	= $(\bar{1}11)$: $(\bar{1}01)$	—		24	45	
o′o′	= $(\bar{1}11)$: $(\bar{1}\bar{1}1)$	—		49	30	
sq	= (101) : (011)	—		38	13	
qp	= (011) : $(\bar{1}10)$	86	21	86	23	2
ps	= $(\bar{1}10)$: $(\bar{1}0\bar{1})$	—		55	24	
pq	= $(\bar{1}10)$: $(0\bar{1}\bar{1})$	93	39	93	37	2
s′q	= $(\bar{1}01)$: (011)	—		45	19	
qn	= (011) : (121)	—		26	48	
np	= (121) : (110)	—		36	48	
qp	= (011) : (110)	63	35	63	36	1
ps′	= (110) : $(10\bar{1})$	—		71	5	
pq	= (110) : $(0\bar{1}\bar{1})$	116	25	116	24	1
r′o′	= $(\bar{2}01)$: $(\bar{1}11)$	—		34	46	
o′p	= $(\bar{1}11)$: (110)	—		92	55	
pr′	= (110) : $(20\bar{1})$	52	25	52	19	6
r′p	= $(\bar{2}01)$: (110)	127	35	127	41	6

Cæsium Cadmium Selenate, $Cs_2Cd(SeO_4)_2 \cdot 6H_2O$.

Crystal System.—Monoclinic. Class No. 5, holohedral-prismatic.

Axial Angles.—$\beta = 106° 22'$.

Ratio of Axes.—$a : b : c = 0{\cdot}7319 : 1 : 0{\cdot}5011$.

Forms observed.—$a\{100\}, b\{010\}, c\{001\}, p\{110\}, p'\{120\}, q\{011\}, r'\{\bar{2}01\}$ $o'\{\bar{1}11\}$.

Habit.—That characteristic of the cæsium salts of the series, prismatic parallel to the inclined axis a, with relatively large faces of $q\{011\}$ and narrower faces of $c\{001\}$. But, like the rubidium salt, the faces of the orthodome $r'\{\bar{2}01\}$ were also generally very prominent. Fig. 2 represents a typical crystal.

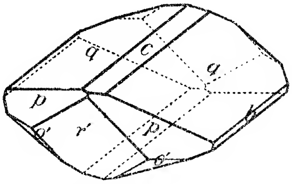

Fig. 2.—Typical crystal of cæsium cadmium selenate.

Cæsium cadmium selenate hexahydrate in general character resembles its rubidium analogue very closely to a large extent, but is distinctly less unstable, the crystals persisting longer when once formed, and often being of large size. But they were only produced during keen frost, and amidst and often deposited upon transparent crystals of the di-hydrate, of which most of the crop was composed.

A greater number of trustworthy measurements were obtained than in the case of the rubidium salt, and are summarised in the accompanying Table. The crystals were always opaque, however, white like porcelain, and eventually became friable.

Cleavage investigations were ambiguous and of little value, although there were indications that the usual cleavage parallel to $r'\{\bar{2}01\}$ is developed.

Density determinations were valueless, and optical investigation an impossibility.

Interfacial Angles of Cæsium Cadmium Selenate.

Angle.	Mean observed.	Calculated.	Diff.
	° ′	° ′	′
$ac = (100) : (001)$	—	73 38	
$as = (100) : (101)$	—	45 2	
$sc = (101) : (001)$	—	28 36	
$cr' = (001) : (\bar{2}01)$	64 35	64 31	4
$cs' = (001) : (\bar{1}01)$	—	38 44	
$s'r' = (\bar{1}01) : (\bar{2}01)$	—	25 47	
$r'a = (\bar{2}01) : (\bar{1}00)$	—	41 51	
$r'c = (\bar{2}01) : (00\bar{1})$	115 25	115 29	4
$ap = (100) : (110)$	—	35 6	
$pp' = (110) : (120)$	19 25	19 28	3
$p'p''' = (120) : (130)$	—	10 4	
$p'b = (120) : (010)$	35 20	35 26	6
$pp''' = (110) : (130)$	—	29 32	
$p'''b = (130) : (010)$	—	25 22	
$pb = (110) : (010)$	54 55	54 54	1
$pp = (110) : (1\bar{1}0)$	70 12	*	
$pp = (110) : (\bar{1}10)$	109 50	109 48	2
$cq = (001) : (011)$	25 41	*	
$qb = (011) : (010)$	—	64 19	
$qq = (011) : (01\bar{1})$	128 38	128 38	0
$ao = (100) : (111)$	—	48 14	
$oq = (111) : (011)$	—	27 3	
$aq = (100) : (011)$	—	75 17	
$qo' = (011) : (\bar{1}11)$	—	35 16	
$o'a = (\bar{1}11) : (\bar{1}00)$	—	69 27	
$co = (001) : (111)$	—	34 9	
$op = (111) : (110)$	—	42 31	
$cp = (001) : (110)$	76 40	*	
$po' = (110) : (11\bar{1})$	58 0	58 5	5
$o'c = (11\bar{1}) : (00\bar{1})$	45 20	45 15	5
$pc = (110) : (00\bar{1})$	103 20	103 20	0
$bn = (010) : (121)$	—	54 40	
$no = (121) : (111)$	—	15 49	
$bo = (010) : (111)$	—	70 29	
$os = (111) : (101)$	—	19 31	
$bo' = (010) : (\bar{1}11)$	—	65 12	
$o's' = (\bar{1}11) : (\bar{1}01)$	—	24 48	
$o'o' = (\bar{1}11) : (\bar{1}\bar{1}1)$	—	49 36	
$sq = (101) : (011)$	—	37 42	
$qp = (011) : (\bar{1}10)$	87 42	87 37	5
$ps = (\bar{1}10) : (\bar{1}0\bar{1})$	—	54 41	
$pq = (\bar{1}10) : (0\bar{1}\bar{1})$	92 18	92 23	5
$s'q = (\bar{1}01) : (011)$	—	45 20	
$qn = (011) : (121)$	—	26 20	
$np = (121) : (110)$	—	36 28	
$qp = (011) : (110)$	62 54	62 48	6
$ps' = (110) : (10\bar{1})$	—	71 52	
$pq = (110) : (0\bar{1}\bar{1})$	117 6	117 12	6
$r'o' = (\bar{2}01) : (\bar{1}11)$	35 3	35 10	7
$o'p = (\bar{1}11) : (110)$	92 30	92 23	7
$pr' = (110) : (20\bar{1})$	52 24	52 27	3
$r'p = (\bar{2}01) : (110)$	127 36	127 33	3

Ammonium Cadmium Selenate, $(NH_4)_2Cd(SeO_4)_2 \cdot 6H_2O$.

Crystal System.—Monoclinic. Class No. 5, holohedral-prismatic.

Axial Angle.—$\beta = 106° 1'$. Topsøe's value, 106° 4′.

Ratio of Axes.—$a : b : c = 0{\cdot}7418 : 1 : 0{\cdot}5026$.

Topsøe's values $0{\cdot}7388 : 1 : 0{\cdot}5001$.

Forms observed.—$a\{100\}$, $b\{010\}$, $c\{001\}$, $p\{110\}$, $p'\{120\}$, $p''\{210\}$, $p'''\{130\}$, $q\{011\}$, $r'\{\bar{2}01\}$, $o'\{\bar{1}11\}$, $n'\{\bar{1}21\}$. The forms a, p'' and n', were not observed by Topsøe.

Habit.—A great variety of habits were exhibited, chiefly, however, more or less tabular parallel either $c\{001\}$ or $r'\{\bar{2}01\}$, and frequently elongated at the same time parallel to the symmetry axis b. A common type is shown in fig. 3, $c\{001\}$ being here the plane of the Table.

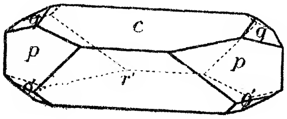

FIG. 3.—A typical crystal of ammonium cadmium selenate.

The crystals were mostly white and opaque, "porcelain-like" as Topsøe describes them. No crystal was found entirely free from white opacity, but a considerable number of crystals were present in certain crops in which there were transparent portions, and advantage was taken of these both in the density determinations and in the optical investigation.

The table of interfacial angles is remarkably satisfactory, considering the difficulty introduced by partial opacity. The signal-images were, indeed, very brilliant, but the limits of the values for the same angle are somewhat wider than has generally been the case in these investigations of this monoclinic series. The mean values, however, are absolutely trustworthy, and agree fairly well with those of Topsøe, which are given in the last column.

Interfacial Angles of Ammonium Cadmium Selenate.

Angle.	No. of measurements.	Limits.	Mean observed.	Calculated.	Diff.	Topsøe's values.
		° ′ ° ′	° ′	° ′	′	° ′
$ac = (100) : (001)$...	1	—	74 0	73 59	1	73 56
$as = (100) : (101)$...	—	—	—	45 15	—	
$sc = (101) : (001)$...	—	—	—	28 44	—	
$cr' = (001) : (\bar{2}01)$...	17	63 58– 64 25	64 15	64 17	2	64 21
$cs' = (001) : (\bar{1}01)$...	—	—	—	38 40	—	
$s'r' = (\bar{1}01) : (\bar{2}01)$...	—	—	—	25 37	—	
$r'a = (\bar{2}01) : (\bar{1}00)$...	2	41 37– 42 1	41 49	41 44	5	
$r'c = (\bar{2}01) : (00\bar{1})$...	18	115 34–116 11	115 46	115 43	3	115 39
$ap = (100) : (110)$...	24	35 11– 35 44	35 30	35 30	0	
$ap'' = (100) : (210)$...	4	19 1– 19 55	19 36	19 38	2	
$p''p = (210) : (110)$...	1	—	15 49	15 52	3	
$pp' = (110) : (120)$...	18	19 3– 19 47	19 26	19 28	2	19 28
$p'b = (120) : (010)$...	14	34 45– 35 25	35 1	35 2	1	35 10
$pp''' = (110) : (130)$...	5	29 12– 29 48	29 29	29 27	2	
$p'''b = (130) : (010)$...	8	24 45– 25 21	24 58	25 3	5	25 9
$p'p''' = (120) : (130)$...	7	9 35– 10 19	10 2	9 59	3	10 1
$pb = (110) : (010)$...	23	54 15– 54 54	54 31	54 30	1	54 38
$pp = (110) : (1\bar{1}0)$...	17	70 43– 71 28	71 0	*	—	70 44
$pp = (110) : (\bar{1}10)$...	16	108 32–109 18	109 0	109 0	0	109 16
$cq = (001) : (011)$...	38	25 23– 26 11	25 47	*	—	25 40
$qb = (011) : (010)$..	20	63 58– 64 49	64 15	64 13	2	64 20
$qq = (011) : (01\bar{1})$...	16	128 14–128 37	128 25	128 26	1	
$ao = (100) : (111)$...	—	—	—	48 28	—	
$oq = (111) : (011)$...	—	—	—	27 9	—	
$aq = (100) : (011)$...	—	—	—	75 37	—	
$qo' = (011) : (\bar{1}11)$...	—	—	—	34 50	—	
$o'a = (\bar{1}11) : (\bar{1}00)$...	—	—	—	69 33	—	
$co = (001) : (111)$...	—	—	—	34 20	—	
$op = (111) : (110)$...	—	—	—	42 41	—	
$cp = (001) : (110)$...	30	76 36– 77 15	77 1	*	—	76 57
$po' = (110) : (11\bar{1})$...	8	57 53– 58 23	58 9	58 5	4	
$o'c = (11\bar{1}) : (00\bar{1})$...	10	44 31– 45 11	44 48	44 54	6	44 47
$pc = (110) : (00\bar{1})$...	30	102 47–103 17	102 59	102 59	0	103 3
$bn = (010) : (121)$...	—	—	—	54 30	—	
$no = (121) : (111)$...	—	—	—	15 52	—	
$bo = (010) : (111)$...	—	—	—	70 22	—	
$os = (111) : (101)$...	—	—	—	19 38	—	
$bn' = (010) : (\bar{1}21)$...	—	—	—	47 9	—	
$n'o' = (\bar{1}21) : (\bar{1}11)$...	—	—	—	17 58	—	
$bo' = (010) : (\bar{1}11)$...	8	64 50– 65 23	65 10	65 7	3	
$o's' = (\bar{1}11) : (\bar{1}01)$...	—	—	—	24 53	—	24 55
$o'o' = (\bar{1}11) : (\bar{1}\bar{1}1)$...	2	49 42– 49 42	49 42	49 46	4	49 51
$sq = (101) : (011)$...	—	—	—	37 52	—	
$qn' = (011) : (\bar{1}21)$...	1	—	35 42	35 47	5	
$n'p = (\bar{1}21) : (\bar{1}10)$...	1	—	51 15	51 20	5	
$qp = (011) : (\bar{1}10)$...	25	86 50– 87 29	87 9	87 7	2	87 16
$ps = (\bar{1}10) : (\bar{1}0\bar{1})$...	—	—	—	55 1	—	
$pq = (\bar{1}10) : (0\bar{1}\bar{1})$...	24	92 31– 93 12	92 50	92 53	3	
$s'q = (\bar{1}01) : (011)$...	—	—	—	45 20	—	
$qn = (011) : (121)$...	—	—	—	26 28	—	
$np = (121) : (110)$...	—	—	—	36 29	—	
$qp = (011) : (110)$...	31	62 36– 63 20	62 56	62 57	1	62 59
$ps' = (110) : (10\bar{1})$...	—	—	—	71 43	—	
$pq = (110) : (0\bar{1}\bar{1})$...	30	116 37–117 29	117 4	117 3	1	
$r'o' = (\bar{2}01) : (\bar{1}11)$...	10	34 40– 35 36	35 3	35 7	4	
$o'p = (\bar{1}11) : (110)$...	9	92 4– 92 40	92 18	92 18	0	92 19
$pr' = (110) : (20\bar{1})$...	26	52 28– 52 57	52 41	52 35	6	52 31
$r'p = (\bar{2}01) : (110)$...	25	127 0–127 44	127 18	127 25	7	127 29
Total (10 crystals) ...	519					

As the only comparisons possible between the three cadmium salts are with respect to the crystal angles and elements, these can be instituted at once, and are made in the accompanying Table.

Comparison of the Interfacial Angles.

Angle.	RbCd selenate.	CsCd selenate.	AmCd selenate.
$ac = (100) : (001)$	74° 53′	73° 38′	73° 59′
$as = (100) : (101)$	45 44	45 2	45 15
$sc = (101) : (001)$	29 9	28 36	28 44
$cr' = (001) : (\bar{2}01)$	63 49	64 31	64 17
$cs' = (001) : (\bar{1}01)$	38 35	38 44	38 40
$s'r' = (\bar{1}01) : (\bar{2}01)$	25 14	25 47	25 37
$r'a = (\bar{2}01) : (\bar{1}00)$	41 18	41 51	41 44
$ap = (100) : (110)$	35 33	35 6	35 30
$pp' = (110) : (120)$	19 28	19 28	19 28
$p'b = (120) : (010)$	34 59	35 26	35 2
$pp''' = (110) : (130)$	29 26	29 32	29 27
$p'''b = (130) : (010)$	25 1	25 22	25 3
$p'p''' = (120) : (130)$	9 58	10 4	9 59
$pb = (110) : (010)$	54 27	54 54	54 30
$cq = (001) : (011)$	25 53	25 41	25 47
$qb = (011) : (010)$	64 7	64 19	64 13
$ao = (100) : (111)$	48 57	48 14	48 28
$oq = (111) : (011)$	27 29	27 3	27 9
$aq = (100) : (011)$	76 26	75 17	75 37
$qo' = (011) : (\bar{1}11)$	34 45	35 16	34 50
$o'a = (\bar{1}11) : (\bar{1}00)$	68 49	69 27	69 33
$co = (001) : (111)$	34 45	34 9	34 20
$op = (111) : (110)$	43 0	42 31	42 41
$cp = (001) : (110)$	77 45	76 40	77 1
$po' = (110) : (11\bar{1})$	57 29	58 5	58 5
$o'c = (11\bar{1}) : (00\bar{1})$	44 46	45 15	44 54
$bn = (010) : (121)$	54 15	54 40	54 30
$no = (121) : (111)$	15 57	15 49	15 52
$bo = (010) : (111)$	70 12	70 29	70 22
$os = (111) : (101)$	19 48	19 31	19 38
$bo' = (010) : (\bar{1}11)$	65 15	65 12	65 7
$o's' = (\bar{1}11) : (\bar{1}01)$	24 45	24 48	24 53
$sq = (101) : (011)$	38 13	37 42	37 52
$qp = (011) : (\bar{1}10)$	86 23	87 37	87 7
$ps = (\bar{1}10) : (\bar{1}0\bar{1})$	55 24	54 41	55 1
$s'q = (\bar{1}01) : (011)$	45 19	45 20	45 20
$qn = (011) : (121)$	26 48	26 20	26 28
$np = (121) : (110)$	36 48	36 28	36 29
$qp = (011) : (110)$	63 36	62 48	62 57
$ps' = (110) : (10\bar{1})$	71 5	71 52	71 43
$r'o' = (\bar{2}01) : (\bar{1}11)$	34 46	35 10	35 7
$o'p = (\bar{1}11) : (110)$	92 55	92 23	92 18
$pr' = (110) : (20\bar{1})$	52 19	52 27	52 35

Comparison of the Axial Angles and Axial Ratios.

	Axial angle.	Axial ratios.
	β.	$a : b : c$
Rubidium cadmium selenate	105° 7′	0·7402 : 1 : 0·5026
Ammonium " "	106° 1′	0·7418 : 1 : 0·5026
Cæsium " "	106° 22′	0·7319 : 1 : 0·5011

The angles of the rubidium and cæsium salts are related just as in the other groups of the series, the signs and amounts of the differences being similar. The angles of the ammonium salt are adequately close to those of the two metallic salts to correspond to true isomorphism, but the relation is, as usual for the ammonium salts, not a eutropic one.

Relative Density.—Four determinations were made by the immersion method, using methylene iodide and benzene mixture.

I.	Density for 16°·2/4°	2·4521	For 20°/4°	2·4512
II.	" 16°·0/4°	2·4514	"	2·4504
III.	" 15°·1/4°	2·4493	"	2·4481
IV.	" 15°·0/4°	2·4521	"	2·4509
			Mean	2·4501

Accepted value for 20°/4°......**2·450**.

Molecular Volume.—$\frac{M}{d} = \frac{538·98}{2·450} = 219·99$.

Topsøe found the specific gravity 2·307, a value much too low, and the molecular volume correspondingly much too high, 235·3.

Molecular Distance Ratios (topic axial ratios).—

$$\chi : \psi : \omega = 6·3045 : 8·4988 : 4·2715.$$

As much reliance as usual, however, cannot be placed on these values for the density and constants dependent on it, as no crystals absolutely transparent throughout could be obtained, the best that could be done being to use such as had the greater part of their substance transparent.

Optical Investigation.—The ordinary procedure could not be followed with the optics for the same reason, that the best crystals were only transparent in parts, the remaining portions being white and opaque like porcelain. The grinding of surfaces for the preparation of plates and prisms was a very difficult task, as opaque portions gave way, and, even when a surface was successfully ground through a transparent part, it rapidly became opaque. After many fruitless efforts, one good 60°-prism, correctly orientated to afford the α and γ indices directly, was, however, successfully ground, and, when fitted with miniature balsam-cemented glass plates, proved beautifully transparent through a sufficient portion of its extent, and gave two excellent spectra corresponding to α and γ. Another prism, a natural one formed by two faces of $q\{011\}$, was also provided by a crystal, one end of which, where these faces were situated, was quite transparent; when this prism was also fitted with glass plates, it afforded two excellent spectra, one spectrum affording β directly, and the other a value near, but not exactly, γ.

The determination of the two refractive indices of this prism thus afforded accurate information as to the intermediate refractive index β of the crystal, and was carried out first, so as to enable a liquid to be chosen which had practically the same index as the mean index for the crystal, monochlorobenzene being indicated. One excellent crystal tabular parallel to $c\{001\}$, like fig. 3, which had been obtained during a very cold night, and which was transparent through a sufficient extent and remained so adequately long, was then used, immersed in this liquid, for (1) the determination of the positions of the two median lines, the bisectrices of the optic axial angle and the axes of the optical ellipsoid lying in the symmetry plane, by observations of the optic axial interference figure; (2) the measurement of the true angle between the optic axes within the crystal; and (3) the determination of the dispersion of the median lines. The knowledge thus obtained of the positions of the axes of the ellipsoid (the third axis of the optical ellipsoid being fixed by the monoclinic symmetry, being the symmetry axis b itself) enabled the refractive index near γ, afforded as the second index by the natural prism formed by two $q\{011\}$ faces, to be corrected to the true value of γ. The value of γ thus obtained proved to be practically identical with that derived directly from the ground prism affording α and γ. In this manner the whole of the optical constants were eventually obtained, and the results are summarised as follows:—

Orientation of Optical Ellipsoid.—The plane of the optic axes is $b\{010\}$, and the sign of the double refraction is positive. The axis α of the indicatrix

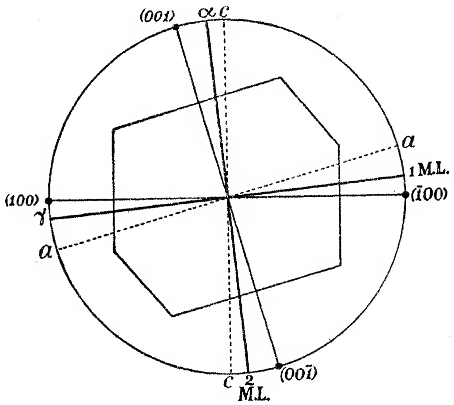

Fig. 4

(ellipsoid) is the second median line, and lies 10° 1′ behind the normal to $c\{001\}$, near to the vertical axis c. As the normal to $c\{001\}$ is 16° 1′ in front of the vertical axis the second median line is 6° 0′ in front of the c-axis. The first median line γ is 10° 1′ above the inclined axis a. Both median lines thus lie in the obtuse angle ac. Fig. 4 will render the situation clear.

Optic Axial Angle.—The values for the true optic axial angle, as measured while the crystal was immersed in monochlorobenzene, were as under, the obtuse angle $2V_o$ being that actually measured, and the values for the acute angle $2V_a$ being given alongside.

Light.	$2V_o$.	$2V_a$.
Li	103° 55′	76° 5′
C	103 49	76 11
Na	103 29	76 31
Tl	103 11	76 49
Cd	103 0	77 0
F	102 47	77 13

Dispersion of the Median Lines.—The median lines showed an extremely small amount of dispersion in the symmetry plane, about 3 minutes being indicated, which is the limit of experimental error.

Refractive Indices.—

Refractive Indices of Ammonium Cadmium Selenate.

Light.	α.	β.	γ.
Li	1·5167	1·5221	1·5311
C	1·5172	1·5227	1·5317
Na	1·5206	1·5260	1·5352
Tl	1·5242	1·5296	1·5386
Cd	1·5262	1·5315	1·5408
F	1·5283	1·5338	1·5427
G	1·5340	1·5393	1·5485

Mean of α, β, and γ for Na light = 1·5273.

α = Vibration direction parallel to second median line, 6° 0′ in front of vertical axis c.
β = „ „ „ symmetry axis b.
γ = „ „ „ first median line, 10° 1′ above inclined axis a.
Double refraction, $\mathrm{Na}_{\gamma-\alpha} = 0·0146$.

General formula for β, corrected to a vacuum :—

$$\beta = 1·5090 + \frac{619\ 700}{\lambda^2} - \frac{543\ 700\ 000\ 000}{\lambda^4} + \ldots .$$

The α indices are equally well reproduced by the formula if the constant 1·5090 be diminished by 0·0054, and the γ indices if it be increased by 0·0091.

Axial Ratios of the Optical Ellipsoid.—

$\alpha : \beta : \gamma = 0{\cdot}9965 : 1 : 1{\cdot}0061, \qquad \mathfrak{a} : \mathfrak{b} : \mathfrak{c} = 1{\cdot}0035 : 1 : 0{\cdot}9940.$

Molecular Optical Constants.

	Axis of optical indicatrix.	α.	β.	γ.
Lorenz	Specific refraction, $\frac{n^2-1}{(n^2+2)d} = \mathfrak{n}$ C	0·1235	0·1246	0·1264
	G	0·1269	0·1279	0·1297
	Molecular refraction, $\frac{n^2-1}{n^2+2} \cdot \frac{M}{d} = \mathfrak{m}$. C	66·57	67·17	68·14
	G	68·38	68·95	69·92
	Specific dispersion, $\mathfrak{n}_G - \mathfrak{n}_C$	0·0034	0·0033	0·0033
	Molecular dispersion, $\mathfrak{m}_G - \mathfrak{m}_C$	1·81	1·78	1·78
Gladstone ...	Molecular refraction, $\frac{n-1}{d} M$ C	113·78	114·99	116·97

Mean molecular refraction (Gladstone), $\frac{1}{3}(\alpha + \beta + \gamma) = 115{\cdot}25$.

General Conclusions concerning the Cadmium Group.

So far as the crystals of this group of three salts have lent themselves to investigation the results are in line with those derived from all the other groups of monoclinic hexahydrated double sulphates and selenates. As regards the crystal angles and elements, which are the only constants that have been completely determinable for all three salts, the relationships are precisely those afforded by the other groups. Hence, if the potassium salt were obtainable the three alkali metallic salts would undoubtedly form a eutropically isomorphous series. The ammonium salt is isomorphous but not eutropic with the alkali metallic salts of the group.

General Remarks on Completion of the Research.

The two papers now published on the manganese and cadmium groups of double selenates form the completion of the task which the author set himself in the year 1890, namely, the thorough detailed investigation of the crystals of the rhombic sulphates and selenates of the alkalies, $R_2\overset{S}{\underset{Se}{}}O_4$, in which R is potassium, rubidium, cæsium, ammonium and thallium, and of the monoclinic hexahydrated double sulphates and double selenates, $R_2M(\overset{S}{\underset{Se}{}}O_4)_2.6H_2O$, in which R represents the same alkali bases and M is magnesium, zinc, iron, nickel, cobalt, copper, manganese and cadmium. Only two of the double salts containing thallium, those in which zinc is the M-metal, have proved suitable as regards perfection of the crystals for inclusion in this research. But, including a group of three analogous double chromates, seventy-five salts in all have been investigated. The work has involved the complete measurement of over 800 crystals (involving altogether 45,000 goniometrical measurements), selected for their special perfection from many crops of each salt, grown under ideal conditions. Over 500 determinations of crystal density have been carried out. More than 2,000 truly plane and accurately orientated polished surfaces have been produced—with the aid of the most efficient and indispensable cutting and grinding goniometer designed for the purpose and described to the Royal Society in the year 1895—in the course of the preparation of the section-plates and 60°-prisms required for the optical portion of the investigation. Moreover, all the optical constants have been determined for a considerable number of specific wave-lengths of light, with the aid of the spectroscopic monochromatic illuminator also devised for the work and described to the Royal Society in 1895, the electric arc being the source of light. The whole has been carried out by the author personally with the exception of the portion concerning the three double chromates, which was carried out jointly by the author and Miss Mary W. Porter. It will now be obvious why the research has occupied so many years, and it is a matter of the deepest satisfaction to the author that he has been permitted to complete it. The results have been published in twenty-six memoirs, besides six other papers describing the new instruments designed specially for this work, but all of which have proved of general application not only to crystallographic but also to ordinary physical investigation and measurement. A complete and chronological list of these memoirs, with full references, is given in an appendix to this paper (p. 262).

The most satisfactory feature of the results is the absolutely unanimous manner in which the individual results for the nineteen different groups confirm each other as regards the relationships of the potassium, rubidium and cæsium salts and the positions of the ammonium and thallium salts of the group. The main conclusions derived from the whole investigation are thus confirmed nineteen times over.

The first of these main conclusions is that the interfacial angles of the crystals, their elements and habits, the volumes and edge dimensions of their space-lattice unit cells, the dimensions and orientations (where variable, in the monoclinic salts) of their optical ellipsoids, their refractive power, the amount of their double refraction, their molecular refractions, their thermal dilatations in the cases where they were determinable (the rhombic simple sulphates), and indeed the minutest details of the structural and physical properties of the crystals, all exhibit a regular progression with the atomic number of the alkali metal ($K = 19$, $Rb = 37$, $Cs = 55$, a difference of eighteen at each step). Indeed, this invariable rule may be considered as a definite law of progression for these rhombic anhydrous oxy-salts of the alkalies and the monoclinic hexahydrated double oxy-salts containing these same alkali bases as the dominating constituents.

The difference in atomic number, eighteen, between potassium and rubidium, and between the latter and cæsium, is interesting; for it corresponds exactly to a whole shell of electrons, according to the Lewis-Langmuir version of the atomic structure theory (or to two shells according to the Bohr-Sommerfeld version). That is to say, when we pass from potassium to rubidium, and again from rubidium to cæsium, we are adding another complete shell of electrons to the structure of the atom, and are obviously adding thereby to the diameter of the atom. Now W. L. Bragg has shown that the atomic diameter is a periodic function of the atomic number, and that the curve representing the atomic diameters of the elements has very sharp maxima at the positions occupied on the curve by the electropositive alkali metals, and more extended minima at the positions of the electronegative elements and of those dyad-acting metals which form weakly acidic or only feebly basic oxides (the M-metals of the monoclinic double salts). The curve of atomic diameters is reproduced in fig. 5 in order to make this point quite clear.

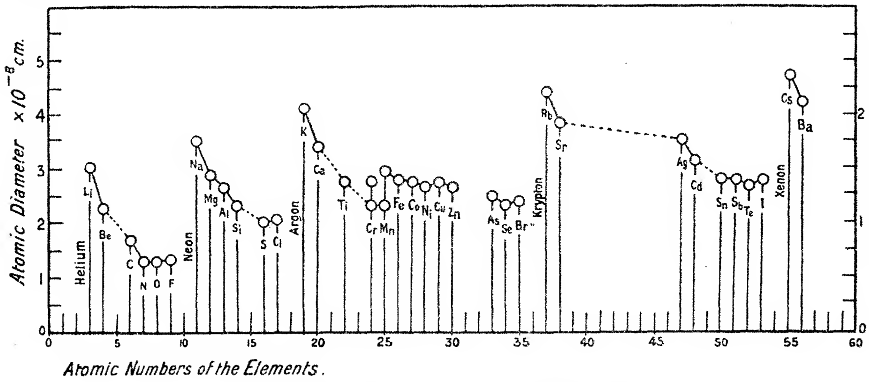

Fig. 5.—The curve of atomic diameters.

Hence these two facts combine to cause the two series of salts chosen for this investigation to be the very best that could possibly have been so selected for the purpose of exhibiting to its greatest extent, and, therefore, most clearly, any differences of crystal form and properties which may be brought about by replacing one element by another of the same family group so as to form another member of the isomorphous series. The fact that the atom of the alkali metal alters in size by a whole electronic shell at each successive interchange, passing thereby from one maximum of the curve to another, higher each time on account of the additional diameter conferred, is thus seen to be the direct cause of the alteration (expansion) of the crystal structure; that is, it is the cause of the alteration of the dimensions of the space-lattice cells, and correspondingly of the perceptible change in the crystal angles (the symmetry remaining the same) and in the optical and other physical properties. Moreover, just as the law of atomic diameters of W. L. Bragg explains completely the author's main result so astonishingly simply, so conversely does this result confirm the accuracy of the law of atomic diameters. Fundamentally, we must go back still further, however, to the law of Moseley, to the fact that the increase of one unit in atomic number means unit accretion of mass (approximately two of atomic weight) and of positive electric charge on the nucleus of the atom and the corresponding addition of a negative electron to the exterior, as the ultimate cause of the progression in the crystallographic properties. Whether we adopt the conception of the sharing of electrons (in the cases of electronegative elements) of the Langmuir version of the atomic structure theory, or the modification thereof by Sir J. J. Thomson, which requires no sharing of electrons, there can be no doubt that no sharing of electrons occurs in the case of the alkali metals. Potassium, rubidium and cæsium possess respectively (as their atomic numbers 19, 37 and 55 indicate) one more electron than required to produce the stable shells of argon (atomic number 18), krypton (atomic number 36), and xenon (atomic number 54). This one extra electron obviously occupies space outside the complete inert gas shell, and is doubtless the monadic valency link or active chemically combining agency characteristic of an alkali metal in the chemical combination with an electronegative element probably actually passing over to the latter, which lacks one or more electrons to complete a stable shell. All versions of the atomic structure theory agree on this. Hence it is that the alkali metals occupy the maxima of the atomic diameter curve, cæsium indeed having the greatest of all the atomic diameters measured, and the change of diametral dimension on passing from one to another is also commensurably considerable, corresponding as already stated to the addition of a shell of eighteen electrons.

Thus it comes about that the choice made in the year 1890, of suitable isomorphous series for studying the changes of crystal structure and properties brought about by the interchange of the replaceable elements of the same family group, has proved so fortunate. At that time we had no inkling of the wonderful nature of the chemical atom, and the manner in which the results of the investigation agree with what could be expected, from atoms constructed as we now know them to be, is highly satisfactory. Moreover, the remarkably dominant influence of the alkali metal in the double salts, compared with the dyad-acting metal, is rendered readily comprehensible.

The second main conclusion is that in every one of the nineteen groups the crystals of the ammonium salt have proved to be practically isostructural with those of the rubidium salt of the same group. This fact has recently been used by A. O. Rankine* to furnish proof of the Langmuir version of the atomic structure theory. For (if that version be correct) as krypton should bear the same relation to rubidium as methane CH_4 does to ammonium NH_4, an atom of krypton should have the same volume as a molecule of methane. Rankine has actually determined the volumes by the viscosity method, and found this to be the case.

A third main conclusion is that the thallium salt of any group also crystallographically resembles the ammonium salt, in being isomorphous but not eutropic (following the law of progression) with the alkali salts, and also in being nearly isostructural with the rubidium salt. The crystals of the thallium salts, however, are sharply distinguished by possessing transcendent refractive power.

The results of this investigation may also be said to have finally settled the old Haüy-Mitscherlich controversy. For they prove that each of even the most similar substances—the members of isomorphous series—is endowed with its own distinctive crystal form and properties. As regards even cubic crystals, for which the angles are fixed by the high symmetry, this is true as regards the physical properties. The work of Sir Henry A. Miers† on the rhombohedral red silver ores, proustite, Ag_3AsS_3, and pyrargyrite, Ag_3SbS_3, proved this for crystal angles, the rhombohedral angles for the two isomorphous substances being respectively 72° 12′ and 71° 22′. But the author's results go further in showing that not only are there real differences of crystal angle between even the most similar non-cubic substances, but that in the case of the most important series of isomorphous oxy-salts formed by the alkali metals the differences exhibit a definite progression with the atomic number of the alkali metal, and thus obey a definite law. The maximum difference of angle observed by the author has been 2° 28′, which occurred between potassium copper and cæsium copper selenates. Moreover, the term "isomorphism" must not be taken absolutely literally, but to mean similarity of a kind which permits these definite small differences of crystal angle, while the symmetry remains identical.

One further result of this investigation has been to show conclusively that —in the cases of members of isomorphous series, for which the type of structure must be identical throughout the series the symmetry being the same—real value attaches to the physical constant molecular volume, the quotient of the molecular weight by the density of the crystals, and to the conception of topic axial ratios or distance ratios, derived by combining the molecular volume with the axial ratios of the crystals. This necessarily implies the great importance of including density determinations of great accuracy in all such crystallographic investigations. For the molecular volume is a relative measure of the volume of the unit cell of the space-lattice of the crystal structure, and the topic axial ratios are the relative measures of the linear edge-dimensions of this unit cell, or the distances (hence the term distance ratios) between the node points of the lattice along the three axial directions. These measures are correctly relative not only for the three sets of edges of the cell of the same substance, but also for the edges of the cells throughout the whole series. This unit cell of the space-lattice is the habitat of the grosser structural unit of the crystal, which is usually the chemical molecule or a small number, two, three or four being common numbers, of chemical molecules; the regular repetition of the representative points, or centres of gravity, of such grosser units forms the space-lattice.

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* 'Nature,' vol. 108, p. 219 (1921).

† 'Min. Mag.,' vol. 8, p. 37 (1888).

The final proof that this is absolute fact was afforded by the X-ray analysis of the rhombic sulphates of potassium, rubidium, cæsium and ammonium, which was carried out with the author's crystals in the laboratory of Sir William Bragg, by Prof. A. Ogg and Mr. F. L. Hopwood.* For the absolute measurements of the spacings and cell dimensions, which they obtained with the X-ray spectrometer, exhibited precisely the relative values published previously by the author. Incidentally also, this X-ray work proved that the second main conclusion of the author above elaborated, that the ammonium salts are almost perfectly isostructural with the analogous rubidium salts is also an absolute fact, and that there could be no possibility of the ammonium salt being built on a different scale, with merely similar relative values. For the absolute values found by X-ray spectrometric analysis, both for the cell volume and cell-edge dimensions, of rubidium and ammonium sulphates, were almost exactly the same. The author used this result, in a special memoir,† finally to disprove the valency volume theory of Pope and Barlow, which required that the volume of ammonium sulphate should be twenty-four, twice that of the rubidium salt, which would be twelve. This conclusion has since been confirmed by W. L. Bragg, who has fixed the sizes of the atoms of a considerable number of the chemical elements, and represented them in his curve of atomic diameters, already referred to and illustrated in fig. 5. These atomic dimensions are totally different from those stipulated by the valency volume theory. A striking example is that offered by a comparison of the sizes of the atoms of cæsium and of nitrogen. According to the valency volume theory cæsium should only have a volume of one, corresponding to its monadic valency, whereas nitrogen should have a volume of three times as much, corresponding to its triadic valency. The truth is, however, just the other way round, for cæsium possesses the largest diameter of any element measured (see the last maximum on the curve, fig. 5), namely, $4{\cdot}75 \times 10^{-8}$ cm. while nitrogen has only an atomic diameter of $1{\cdot}30 \times 10^{-8}$ cm., less than a third of the diameter of the atom of cæsium. The law of atomic diameters now, therefore, replaces the valency volume theory; for the idea that the size of the atoms has much to do with crystal structure was sound, but the real sizes are far removed from what was supposed by the valency volume theory, namely, that they were proportional to the valency of the element. With this law of atomic diameters of W. L. Bragg, however, the author's results have been shown to be in full agreement.

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* 'Phil. Mag.,' vol. 32, p. 518 (1916).

† 'Roy. Soc. Proc.,' A, vol. 93, p. 72 (1917).

Thus it has come about, by the time that the author has completed his crystallographic investigation of these important isomorphous series, that a full explanation of the results is afforded by the immense amount of real knowledge that has been accumulated during the same time concerning the structure and nature of the chemical atom, and that revealed by means of the powerful new weapon of research, analysis by means of X-rays, from which the law of atomic diameters has been derived. It is thus highly satisfactory that the work of Moseley, Sir J. J. Thomson, Langmuir, the Braggs and the author should so perfectly agree in giving us a wider and fuller understanding of the nature of crystals, and of the structure of the solid matter of which they are the organised expression, than could have been expected or anticipated at the time when the author's researches on these isomorphous series were initiated.

APPENDIX.

List of Memoirs Communicating the Results of the Research.

1. Connection between the atomic weight of contained metals and the magnitude of the angles of crystals of isomorphous salts. A study of the potassium, rubidium, and cæsium salts of the monoclinic series of double sulphates $R_2M(SO_4)_2{\cdot}6H_2O$.

'Journ. Chem. Soc. Trans.,' vol. 63, p. 337 (1893); 'Z. f. Kryst.,' vol. 21, p. 491 (1893).

2. Connection between the atomic weight of contained metals, and the crystallographical characters of isomorphous salts. A comparative crystallographical study of the normal sulphates of potassium, rubidium and cæsium.

'Journ. Chem. Soc. Trans.,' vol. 65, p. 628 (1894); 'Z. f. Kryst.,' vol. 24, p. 1 (1895).

3. The volume and optical relationships of the potassium, rubidium and cæsium salts of the monoclinic series of double sulphates.

'Journ. Chem. Soc. Trans.,' vol. 69, p. 344 (1896); 'Z. f. Kryst.,' vol. 27, p. 113 (1897).

4. Comparison of the results of the investigations of the simple and double sulphates containing potassium, rubidium and cæsium, and general deductions therefrom concerning the influence of atomic weight on crystal characters.

'Journ. Chem. Soc. Trans.,' vol. 69, p. 495 (1896); 'Z. f. Kryst.,' vol. 27, p. 252 (1897).

5. The bearing of the results of the investigations of the simple and double sulphates containing potassium, rubidium and cæsium on the nature of the structural unit.
'Journ. Chem. Soc. Trans.,' vol. 69, p. 507 (1896); 'Z. f. Kryst.,' vol. 27, p. 266 (1897).

6. A comparative crystallographical study of the normal selenates of potassium, rubidium and cæsium.
'Journ. Chem. Soc. Trans.,' vol. 71, p. 846 (1897); 'Z. f. Kryst.,' vol. 29, p. 63 (1898).

7. The thermal deformation of the crystallised normal sulphates of potassium, rubidium and cæsium.
'Phil. Trans.,' A, vol. 192, p. 455 (1899); 'Z. f. Kryst.,' vol. 31, p. 426 (1899).

8. A comparative crystallographical study of the double selenates of the series $R_2M(SeO_4)_2.6H_2O$. Salts in which M is zinc.
'Proc. Roy. Soc.,' A, vol. 66, p. 248, and vol. 67, p. 58 (1900); 'Z. f. Kryst.,' vol. 33, p. 1 (1900).

9. A comparative crystallographical study of the double selenates of the series $R_2M(SeO_4)_2.6H_2O$. Salts in which M is magnesium.
'Phil. Trans.,' A, vol. 197, p. 255 (1901); 'Z. f. Kryst.,' vol. 35, p. 529 (1902).

10. Crystallised ammonium sulphate and the position of ammonium in the alkali series.
'Journ. Chem. Soc. Trans.,' vol. 83, p. 1049 (1903); 'Z. f. Kryst.,' vol. 38, p. 602 (1904).

11. The relation of ammonium to the alkali metals. A study of ammonium magnesium and ammonium zinc sulphates and selenates.
'Journ. Chem. Soc. Trans.,' vol. 87, p. 1123 (1905); 'Z. f. Kryst.,' vol. 41, p. 321 (1905).

12. Topic axes, and the topic parameters of the alkali sulphates and selenates.
Journ. Chem. Soc. Trans.,' vol. 87, p. 1183 (1905); 'Z. f. Kryst.,' vol. 41, p. 381 (1905).

13. Ammonium selenate and the question of isodimorphism in the alkali series.
'Journ. Chem. Soc. Trans.,' vol. 89, p. 1059 (1906); 'Z. f. Kryst.,' vol. 42, p. 529 (1907).

14. The relation of thallium to the alkali metals. A study of thallium sulphate and selenate.
'Proc. Roy. Soc.,' A, vol. 79, p. 351 (1907); 'Z. f. Kryst.,' vol. 44, p. 113 (1907).

15. The relation of thallium to the alkali metals. A study of thallium zinc sulphate and selenate.
'Proc. Roy. Soc.,' A, vol. 83, p. 211 (1909); 'Z. f. Kryst.,' vol 48, p. 190 (1910).

16. Crystallographic constants and isomorphous relations of the double chromates of the alkalies and magnesium (in collaboration with Miss Mary W. Porter).
'Mineralog. Mag.,' vol. 16, p. 169 (1912); 'Z. f. Kryst.,' vol. 51, p. 53 (1912).

17. Ammonium ferrous sulphate and its alkali-metal isomorphs.
'Proc. Roy. Soc.,' A, vol. 88, p. 361 (1913); 'Z. f. Kryst., vol. 52, p. 433 (1913).

18. The monoclinic double sulphates containing ammonium. Completion of the double sulphate series. 'Phil. Trans.,' A, vol. 216, p. 1 (1915).

19. Monoclinic double selenates of the nickel group.
'Phil. Trans.,' A, vol. 217, p. 199 (1917).

20. X-ray analysis and topic axes of the alkali sulphates, and their bearing on the theory of valency volumes. 'Proc. Roy. Soc.,' A, vol. 93, p. 72 (1917).

21. Selenic acid and iron. Reduction of selenic acid by nascent hydrogen and hydrogen sulphide. Preparation of ferrous selenate and double selenates of iron group.
'Proc. Roy. Soc.,' A, vol. 94, p. 352 (1918).

22. Monoclinic double selenates of the iron group.
'Phil. Trans.,' A, vol. 218, p. 395 (1919).

23. Monoclinic double selenates of the cobalt group.
'Proc. Roy. Soc.,' A, vol. 96, p. 156 (1919).

24. Monoclinic double selenates of the copper group.
'Proc. Roy. Soc.,' A, vol. 98, p. 67 (1920).

25. Monoclinic double selenates of the manganese group.
'Proc. Roy. Soc.,' A, vol. 101, p. 225 (1922).
26. Monoclinic double selenates of the cadmium group.
'Proc. Roy. Soc.,' A, vol. 101, p. 245 (1922).

MEMOIRS CONCERNING NEW INSTRUMENTS FOR THE RESEARCH.

1. An instrument for grinding section-plates and prisms of crystals of artificial preparations accurately in the desired directions.
'Phil. Trans.,' A, vol. 185, p. 887 (1895); 'Z. f. Kryst.,' vol. 24, p. 433 (1895).
2. An instrument of precision for producing monochromatic light of any desired wave-length, and its use in the investigation of the optical properties of crystals.
'Phil. Trans.,' A, vol. 185, p. 913 (1895); 'Z. f. Kryst.,' vol. 24, p. 455 (1895).
3. An instrument for cutting, grinding and polishing section plates and prisms of mineral or other crystals accurately in the desired directions.
'Proc. Roy. Soc.,' A, vol. 57, p. 324 (1895); 'Z. f. Kryst.,' vol. 25, p. 79 (1896).
4. A compensated interference dilatometer.
'Phil. Trans.,' A, vol. 191, p. 313 (1898); 'Z. f. Kryst.,' vol. 30, p. 529 (1899).
5. Verbesserungen an den Apparate zum Schneiden, Schleifen, und Poliren genau orientirter Krystallplatten. 'Zeitschr. für Kryst.,' vol. 31, p. 458 (1899).
6. The elasmometer, a new interferential form of elasticity apparatus.
'Phil. Trans.,' A, vol. 202, p. 143 (1904); 'Z. f. Kryst.,' vol. 39, p. 321 (1904).

Magnetism and Atomic Structure.—II. *The Constitution of the Hydrogen-Palladium System and other similar Systems.*

By A. E. OXLEY, M.A., D.Sc., F.Inst.P.

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1. INTRODUCTION.

The present work is a continuation of that published in 'Phil. Trans., A, vol. 214, pp. 109–146 (1914); A, vol. 215, pp. 79–103 (1915); A, vol. 220, pp. 247–289 (1920); 'Roy. Soc. Proc.,' A, vol. 95, p. 58 (1918), and A, vol. 98, p. 264 (1921). It was believed that a magnetic examination of the properties of palladium black which had been charged with hydrogen would enable us to decide which of the proposed constitutions is the correct one. If the hydrogen were in the atomic state and *free,* one might expect that the system would be more magnetic than uncharged palladium black, whether the assumed constitution of the hydrogen atom be that of Bohr* or

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* Sommerfeld, 'Atombau u. Spectrallinien,' p. 239, *et seq.*